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PERFORMANCE ESTIMATES FOR ATTACHED-SUNSPACE PASSIVE SOLAR HEATED BUILDINGS*

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ABSTRACT

Performance predictions have been made for attached-sunspace types of passively solar heated buildings. The predictions are based on hour-by-hour computer simulations using computer models developed in the framework of PASOLE, the Los Alamos Scientific Laboratory (LASL) passive solar energy simulation program. The models have been validated by detailed comparison with actual hourly temperature measurements taken in attached-sunspace test rooms at LASL.

1. INTRODUCTION

For the purpose of performance predictions, a building is characterized by certain parameters that specify its thermal properties. Two parameters of critical importance are the building load coefficient (BLC) and the solar collection area (A_c). The BLC is the building steady-state heat loss per degree of temperature difference per unit time, usually in units Btu/F day. The single most important building variable in determining solar heating performance is the ratio of the two, the load/collector ratio (LCR):

$$LCR = BLC/A_c \ . \tag{1}$$

For a given location and building design, knowledge of this parameter alone is sufficient to determine a reasonably accurate estimate of the average annual building performance. The BLC should be the net BLC in which are included neither solar gains nor steady-state losses through the south solar wall. A warning is appropriate, however, that in the solar/load ratio to be discussed below, the building load is sometimes characterized by a gross BLC that does include the effect of steady-state losses through the solar wall.

Because of the possible variety of glazing geometries in a sunspace, there is potential ambiguity in the definition of A_c. (Should it include all south-facing glass, or just areas projected on a vertical plane? Should any credit be given to glazed east or west end walls, or to glazings with other orientations?) To resolve this ambiguity in a simple way, A_c for sunspaces is defined to be the area of the principal glazing projected on a vertical plane. The principal glazing may consist of two or more planes of different tilts, but they should all be oriented toward the same azimuth (normally due south). Glazings with other azimuths, such as east and west end walls, are not included in A_c.

A site-specific variable that incorporates the building information of the LCR with information about the average temperature and sunshine at the location of the building is the solar/load ratio (SLR). The SLR is the ratio of the sunlight absorbed in the sunspace (Q_s) over some period of interest, usually a month, to a building reference thermal load (Q_{load}) over the same period:

$$SLR = Q_s/Q_{load} \ . \tag{2}$$

The quantity Q_{load} equals BLC x DD where DD is the integrated positive temperature difference between a reference indoor temperature and the outdoor ambient air temperature over the time period of interest. Normally, DD is the monthly sum of 65F reference heating degree days. An alternative expression of the SLR, and the one most convenient for performance estimation, is

$$SLR = S/(DD \times LCR) \ , \tag{3}$$

where S is Q_s/A_c, the sunlight absorbed in the sunspace per unit of collection area. Performance predictions are summarized by a solar savings fraction (SSF), which is the ratio of the

*Work performed under the auspices of the US Department of Energy, Office of Solar Applications.

conventional heating energy saved due to the solar system to the total heating energy requirement of a similar, but "non-solar," building. Here, a "non-solar" building is one that is identical to the solar one but through whose south solar wall there is no net heat gain or loss. Specifically, the SSF is calculated with the equation

$$SSF = (Q_{load} - Q_{aux})/Q_{load} , \qquad (4)$$

where Q_{aux} is the auxiliary heat required by the residential space and the sunspace to keep their temperatures at or above the thermostat set points, and Q_{load} is the reference heating load, BLC x DD. This BLC does not include gains or losses through the south solar wall.

Correlations exist between the monthly SSF and the monthly SLR. These correlations are the basis of an SLR method, which was originally developed as a design tool for active systems,[1] for estimating the performance of solar heated buildings. Later the technique was adapted to passive systems and applied to thermal storage wall buildings by Balcomb and McFarland,[2] and then to direct-gain buildings by Wray, Balcomb, and McFarland.[3] The current status of this method of performance estimation for passive systems is available in handbook form.[4] The present paper reports the application of the SLR method to attached-sunspace buildings.

The SLR is essentially a correlating parameter, and modifications of it have been developed that are useful in developing the best correlations. For the thermal storage wall and direct gain buildings, the modified SLR includes the effect of steady-state heat losses through the south solar wall. It can be written as Q_s/Q_{load}' or S/(DD x LCR'), analogous to Eqs. 2 and 3, but with primes to signify that the load includes a term for the steady-state loss through the solar wall with no solar radiation on it. LCR' is LCR + G, where G represents the steady-state heat load coefficient for the solar wall per unit of collection area. The actual determination of G for use in performance estimation methods is through the least-squares fitting procedure used in the development of the SSF-versus-SLR correlations. A different modification to the SLR is needed in SSF-versus-SLR correlations for attached-sunspace buildings, as described in Section 3.

2. THE REFERENCE DESIGNS

Sixteen representative reference designs have been chosen for performance predictions, based on two sunspace geometries. The geometries consist of one with a south glazing in a single plane tilted at 50° from the horizontal (Fig. 1a); and another with two south glazing planes, a 1.83-meter (6-ft) high vertical plane and a 30° tilted one above it (Fig. 1b).

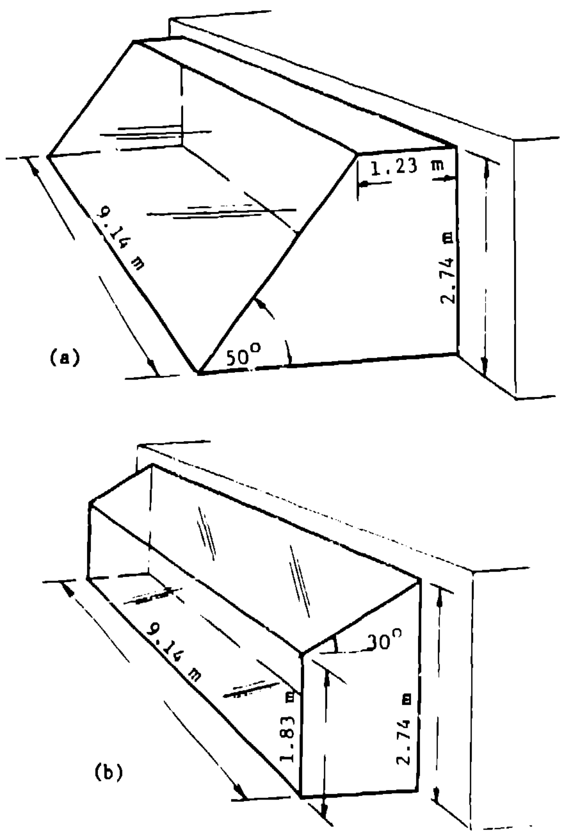

Fig. 1. Sunspace geometries. Both are 2.74 m (9 ft) high by 9.14 m (30 ft) wide. In (a) there is a single south glazing tilted at 50°, and an insulated ceiling 1.23 m (4 ft) deep. In (b) there are two south glazings: a vertical one 1.83 m (6 ft) high and a 30° tilted one. In either geometry, the end walls may be glazed or insulated.

Two wall configurations were investigated, one with a masonry thermal storage wall separating the sunspace from the adjacent space, and the other with thermal storage in the form of a water container in the sunspace and an insulated wall separating the sunspace from the adjacent residential space. The former configuration resembles a Trombe wall building in function, but with a usable space between the glazing and the absorber wall. The latter configuration corresponds to the addition of a sunspace to an existing, insulated building. In either case, heat may be transferred from the sunspace to the adjacent residential space by conduction through the wall or by natural thermocirculation through vents, but, in the insulated wall, heat transfer will be primarily by thermocirculation. Each of these two basic wall configurations comprises four different designs: with insulated or glazed east and west sunspace end walls, and with and without nighttime insulation on the sunspace glazing.

In the insulated wall configuration, the thermal storage water container extends the full 30-ft width of the sunspace. It is rectangular in cross section, 1.29 m (4.24 ft) high and 0.65 m (2.12 ft) deep. The container is immediately adjacent to, but detached from, the sunspace floor and wall; it is thermally coupled to them by radiation and indirectly by convection through the sunspace air.

The south glazing, and the east and west end walls when glazed, are assumed to be perfectly diffusing in the forward direction. They scatter the transmitted radiation isotropically into a hemisphere inside the sunspace. The radiation eventually absorbed by each interior surface is the result of multiple internal reflections.

A summary of the characteristics of the reference designs follows:

Thermal storage:
- 0.613 MJ/C m^2 (30 Btu/F ft^2) of south wall (masonry),
- 1.337 MJ/C m^2 (62.4 Btu/F ft^2) of south wall (insulated);
- Double glazing, diffusing, with normal transmittance = .747, spacing = 12.7 mm (0.50 in.);
- Room temperature control range = 18.2C to 23.9C (65F to 75F);
- Sunspace temperature control range = 7.2C to 35C (45F to 95F);
- Thermal resistance of night insulation (when used) is 1.59 m^2 C/W (R9), in place 5 pm to 8 am;
- Thermal mass-to-air conductance = 8.52 W/m^2 C (1.5 Btu/F hr ft^2);

Masonry properties (masonry wall):
- Thermal conductivity (k) = 1.38 W/m C (0.8 Btu/ft hr F);
- Density (ρ) = 2403 kg/m^3 (150 lb/ft^3);
- Specific heat (c) = 837 J/kg C (0.2 Btu/lb F);
- Infrared emittance of mass surface = 0.9;
- Sunspace solar absorptances
  South wall or storage container = 0.9
  Floor = 0.8
  Other surfaces = 0.3;
- Ground reflectance = 0.3, no shading;
- Wall has vents at top and bottom with backdraft dampers, vent area = 3% of wall area (each of two vents);
- No internal heat generation.

Aside from heat losses through the glazings, sunspace losses include those through insulated top and end walls with an overall heat transfer coefficient of 0.284 W/m^2 C (0.05 Btu/hr ft^2 °F), air infiltration at 0.2 air changes per hour and small perimeter losses (no evaporation losses).

3. THE SOLAR/LOAD RATIO CORRELATIONS

Correlations have been developed for use as performance estimation tools between monthly SSFs and monthly modified SLRs. The data base for the correlations consists of the results of year-long, hour-by-hour computer simulations. The simulation models were developed in the framework of PASOLE, the Los Alamos Scientific Laboratory (LASL) passive solar energy simulation program. The models have been validated by detailed comparisons with actual, hourly temperature measurements taken during the 1979-80 winter season in two attached-sunspace test buildings at LASL. There was one run for each of 80 building configurations (16 reference designs, and 5 values of the LCR for each design) in each of 24 cities, a total of 1920 runs. The simulations were driven by the hourly typical meteorological year (TMY) for each city.

The modified SLR was used as a correlating parameter in which were included the effect of steady-state heat losses from the sunspace to ambient. These effects were incorporated by subtracting them from Q_s (refer to Eq. 2). The modified SLR has the form

$$SLR' = (S - LCR_s \times DD \times H)/(DD \times LCR), \qquad (5)$$

where LCR_s is the load/collector ratio for the sunspace. The parameter H is determined through the correlation procedure as described below.

The SSF-versus-SLR correlating function is

$$SSF = \begin{cases} AX, \text{ for } X < R \\ B - C \exp(-DX), \text{ for } X > R, \end{cases} \qquad (6)$$

$$\text{where } X = SLR', \qquad (7)$$

with the additional constraint that SSF is never greater than one. Then, the parameters A, B, C, D, and H are chosen so that the squares of the deviations of the annual SSFs are minimized. In obtaining the best values of H, the following values of the sunspace load parameter, LCR_s, were assumed:

LCR_s: kJ/m^2 C-day (Btu/ft^2 F-day)

Case*	Geometry (a)	Geometry (b)
1. No NI, IE	359 (17.6)	321 (15.7)
2. NI, IE	192 (9.4)	161 (7.9)
3. No NI, GE	462 (22.6)	180 (18.8)
4. NI, GE	233 (11.4)	186 (9.1)

*See Table 1.

To illustrate the results, Fig. 2 compares the individual monthly SSF simulation results (symbols) with the correlation function estimate from Eq. 6 (solid line) for one reference design, the case of sunspace geometry (a) (Fig. 1a) with masonry thermal storage wall, opaque end walls, and no night insulation. Figure 3 illustrates the correlation between the annual SSFs for the same reference design. The correlation function coefficients and standard deviations in annual SSF are shown in Table 1. These correlations were developed using the equation for 5 given in Section 4.2. The first four correlations in Table 1 are only slightly worse than the correlations for individual reference designs for these four cases.

The present correlations give systematic deviations from the hour-by-hour results. The SSFs predicted for Albuquerque, for

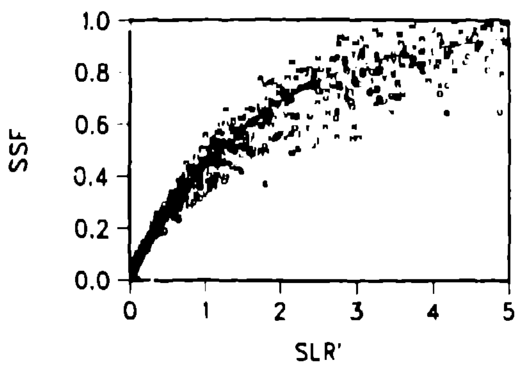

Fig. 2. Monthly SSF vs. monthly SLR' for sunspace geometry (a) with Trombe wall, opaque end walls, and no night insulation.

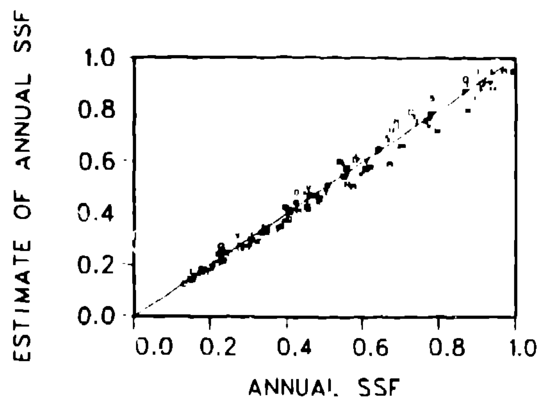

Fig. 3. Comparison of annual SSFs estimated by the SLR method and calculated by simulation, Sunspace geometry (a) with Trombe wall, opaque end walls, and no night insulation.

instance, will be roughly 5% lower than the PASOLE results, while those for Lake Charles, LA, will be 5 to 7% high. More work will be done on the correlations in an attempt to remove the systematic deviations.

4. PERFORMANCE ESTIMATION

4.1. The Tabular Method

The SSF-versus-SLR correlation expressed by Eq. 6 is the basis of two methods of performance estimation. The first and simplest is to make use of tables based on Eq. 6. Space limitation prevents the inclusion of these tables in the published proceedings, but they are included in an

TABLE 1

COEFFICIENTS FOR SSF-VERSUS-SLR CORRELATION FUNCTION

	H	R	A	B	C	D	σ
I. TW and IW; both geometries							
1. IE (Case 1)	0.91	0.6013	0.4925	0.9617	1.039	0.7400	.032
2. NI, IE (Case 2)	0.99	0.9414	0.5514	0.9679	1.463	1.278	.028
3. GE (Case 3)	0.85	0.5904	0.4[illegible]22	0.9476	1.008	0.6645	.034
4. NI, GE (Case 4)	0.99	0.9244	0.5433	0.9710	1.368	1.159	.028
5. All Cases combined	0.92	0.9610	0.5084	0.9436	1.331	1.117	.041
II. TW and IW; Geometry (a), combined cases	0.91	0.9877	0.5003	0.9486	1.348	1.101	.041
III. TW and IW; Geogetry (b) combined cases	0.93	0.9775	0.5156	0.9313	1.390	1.206	.040
IV. TW; both geometries combined cases	0.90	0.8214	0.5163	0.9522	1.179	0.9777	.038
V. IW; both goemetries combined cases	0.94	1.0994	0.5023	0.9361	1.618	1.308	.043

TW = Trombe wall (masonry thermal storage wall)
IW = Insulated wall (with thermal storage in water container in sunspace)
NI = Night insulation
IE = Insulated end walls
GE = Glazed end walls
Geometry (a), see Fig. 1a, Geometry (b), see Fig. 1b

extended version of the paper, which is available from the authors and which will be published elsewhere. The tables list values of the SSF for more than 200 locations, for each of four cases, and for a series of building LCR values. The estimation procedure, then, is to (1) determine the building LCR, (2) go to the tables under the desired location, and (3) interpolate between the given LCR values for the SSF estimate.

4.2. The Monthly SLR Method

If a desired location is not among the tabulated ones, or if a month-by-month performance estimation is desired, or if other design considerations do indicate, then the monthly SLR method is available. In this method, the analyst must use Eq. 6 directly for each month. The inputs required (from Table 1 and Eqs. 5 and 6) are all straightforward except S in Eq. 5, the monthly solar radiation absorbed in the sunspace per unit collection area. The information that normally is available is the total, monthly radiation on a horizontal surface, Q_h. To determine S, simple correlations were developed for the ratio S/Q_h as a function of the latitude minus the mid-month solar declination, L-D, and the ratio of monthly total horizontal-to-monthly extra terrestrial radiations, Q_h/Q_{he}. The data points were taken from the hour-by-hour simulations for 24 cities. There is one set of correlations for each of the four glazing geometries: geometry (a) with and without glazed end walls, and geometry (b) with and without glazed end walls. Double glazing and a ground-reflectivity of 0.3 were assumed. Hourly direct normal radiation was obtained from the TMY weather files as well as total horizontal. Reflections and absorptions at each glazing were calculated on the basis of the optical properties of ordinary, double-strength window glass. The results are expressed by Eq. 8 and in Table 2, the coefficients. In the table, the values are the standard deviations of the correlations.

$$\frac{S}{Q_h} = A_1 + A_2X + A_3X^2 + A_4Z + A_5XZ + A_6X^2Z, \quad (8)$$

where $X = (L-D)/100$ (deg.), $Z = Q_h/Q_{he}$.

5. ACKNOWLEDGMENT

The authors are grateful for the able technical assistance of Gloria Lazarus in the computations reported herein.

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TABLE 2

TABLE OF COEFFICIENTS FOR SOLAR RADIATION CORRELATIONS

Glazing/Geometry	A_1	A_2	A_3	A_4	A_5	A_6	σ
IE, Geometry (a)	0.677	-0.1041	0.437	-0.1329	0.1050	3.41	.057
GE, Geometry (a)	0.721	-0.1578	0.489	-0.1441	0.244	2.88	.048
IE, Geometry (b)	0.533	-0.0685	0.360	-0.1453	-0.257	3.40	.045
GE, Geometry (b)	0.541	-0.0920	0.374	-0.1442	-0.1646	3.03	.040

IE = Insulated end walls
GE = Glazed end walls